CEMENT AND LIME MANUFACTURE

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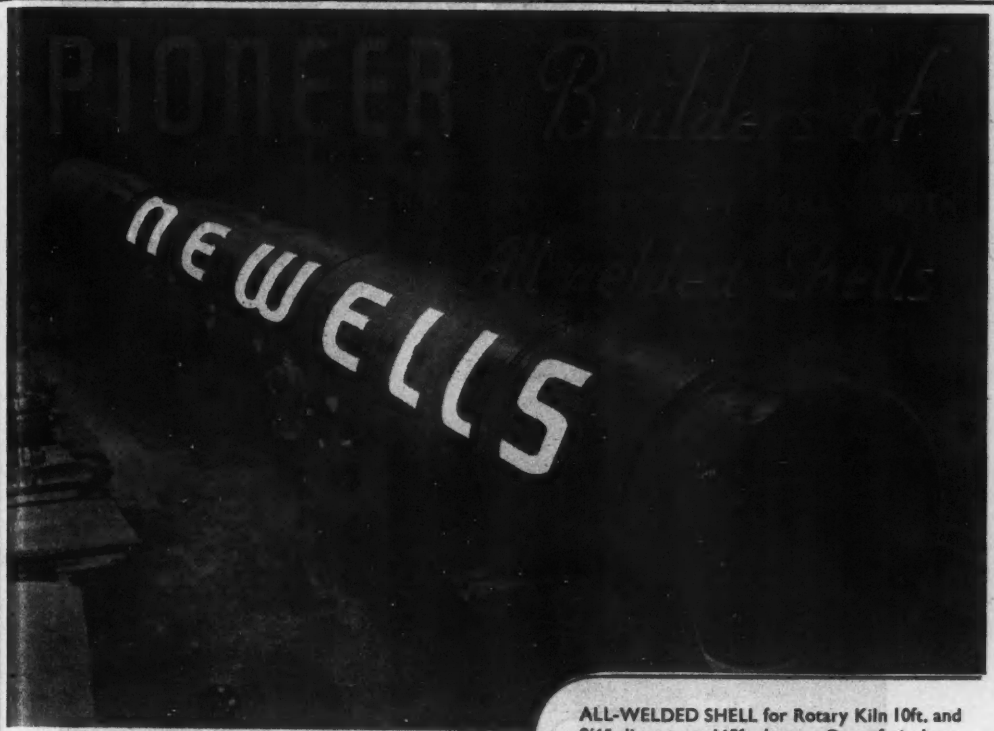
VOL. XXI. No. 3 Seattle, Wash. MAY 1948 PRICE 1/- ALTERNATE MONTHS



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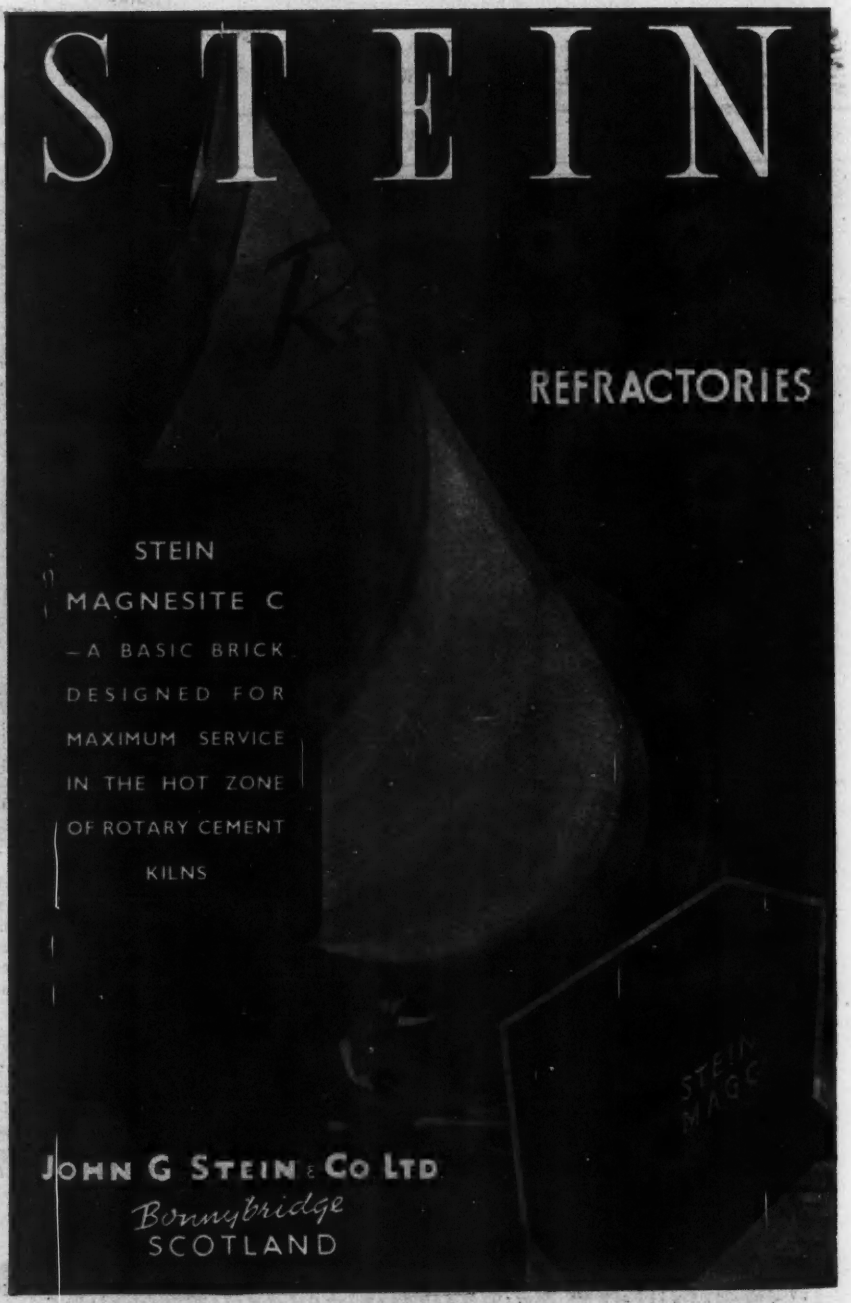
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14 DARTMOUTH STREET, LONDON, S.W.1
TELEPHONE: WHITEHALL 4581.
TELEGRAPHIC ADDRESS:
CONCRETIUS, PARL. LONDON.

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VOLUME XXI. NUMBER 3 MAY, 1948

The Chemistry of Portland Cement.

IN a book* published recently, Mr. R. H. Bogue considers exhaustively most of the aspects of the chemistry of the raw materials, manufacture, and hardening of Portland cement. Although the book contains nearly six hundred pages, the author keeps strictly within the bounds indicated by the title and makes only passing references to the physical properties, such as fineness, or to high-alumina or other non-Portland cements.

The history of the cement industry is traced from the calcined impure gypsum used by the early Egyptians, the calcined limestone, volcanic tuff, and the pozzolana used centuries later by the Greeks and Romans, and the hydraulic cements of the eighteenth century to the invention and subsequent development of Portland cement. Brief descriptions of the various kinds of cements are given, and the requirements of five kinds used in the United States are summarised. The manufacture of Portland cement is treated from the point of view of the chemical problems of modern cement works. The effect of the composition, burning and cooling of the clinker on the colour of the ground clinker is discussed. Although fine grinding of the clinker may cause an hydrated cement to develop its strength more rapidly, this very quality, states Mr. Bogue, may deprive the cement of a reserve of hydratable material which would otherwise be of great value.

The first of the three principal parts of the book deals with the chemistry of the clinker. Early speculation and later experiments on the constitution of Portland cement are described. Le Chatelier was probably the first to realise that chemical analysis reveals little of the nature of the compounds formed during fusion and crystallisation, and he was the first to examine the material microscopically. The researches of Le Chatelier and of Tornebohm, who identified the crystalline constituents alite, belite, celite, and felite, are the basis of many of the theories of the constitution of Portland cement. The hypotheses of solid solutions, with which W. Michaelis, among others, is associated, were put forward

* "The Chemistry of Portland Cement." By R. H. Bogue. (London: Chapman and Hall. 1947. Price 60s.)

in the early years of the present century, to be followed by theories based on structural or constitutional formulæ, concerning which Mr. Bogue states that there is much speculation but little evidence.

The processes of calcination, and the accompanying volatization of some of the alkalis, such as potash, the thermal reactions during the formation of the clinker, and the necessity of controlling the cooling are the subjects of a separate chapter. The temperature during burning is not sufficiently high to liquify all the raw materials, and some of the reactions may take place between solids and liquids, or even between solids. The time required for the reactions to be completed depends on many conditions, mainly physical, and the reactions may continue during cooling. Thus the rate of cooling to maintain equilibrium differs with the composition ; rapid cooling causes some of the fused materials to solidify as glass instead of crystallizing. The reactions in the solid state, and the effects of composition and the sizes of the particles, are some of the matters considered in connection with the combination of the components.

Descriptions of methods of examination of clinker, such as petrographic, X-ray, electron microscopic, spectrographic, and polarographic, and chemical methods and the heat of solution method, precede a discussion on the principal constituents of clinker, in which the controversy that until 1931 had raged for 50 years around the problem of whether or not alite is tricalcium silicate is recounted and solved in the affirmative. The α–β and β–γ inversions of dicalcium-silicate, the identification of free lime and periclase, the various suggestions concerning the interstitial materials, and the crystal structure of the compounds of Portland cement are other matters studied, and the indecisiveness of the conclusions and the necessity for further research in many of these matters are emphasised.

The chemical bases of the many devices and formulæ that have been proposed for the production of a clinker having a predetermined composition are considered together with the validity of the methods, many of which are disputable, of identifying and measuring the phases produced. The results of some methods are compared.

The second part of the book deals with the phase equilibria of the components of the clinker. The derivation and application of the phase rule is given, and binary and polycomponent systems are considered, proceeding from the simplest type of phase equilibrium, that is when there are no reactions between the components of the system. The procedures of high-temperature phase research are elaborated. The system $CaO.Al_2O_3.SiO_2$ (these three oxides constitute over 90 per cent. of commercial Portland cement), and systems containing MgO with CaO, Al_2O_3, and SiO_2, either singly, in pairs, or all together, and the ferrous oxide and titania systems are successively considered. Other systems studied are Fe_2O_3 with CaO and SiO_2 ; MgO and Fe_2O_3 with CaO and Al_2O_3, and with CaO, Al_2O_3, and SiO_2 ; and systems containing K_2O or Na_2O and Li_2O.

The third part is a summary of the theories of the hydration of Portland cement, commencing with a comparison of the crystallisation theory of Le Chatelier and the colloidal theory of Michaelis, from which it is concluded that the

present tendency seems to be to accept the general principles of the crystallisation theory but to recognise the important part played by amorphous material, and that in fact, as stated by Dr. Kühl in our number for January, 1948, there is not so much difference between the two theories. The chemical nature of the setting and hardening processes and the chemical significance of the rate of setting are considered, and five explanations are given of the probable manner in which the gypsum affects the hydration of the calcium aluminate. The structure of hydrated cements is studied and copiously illustrated. The currently-held theories of setting, that is the change from a fluid to a rigid state of the cement paste and which is closely associated with changes of temperature in the paste, and the heat evolved during hydration are examined. The author refers to a paper by Professor M. Gary published in "Concrete and Constructional Engineering," November, 1906, wherein it is established that the arbitrary initial set corresponds closely to the time in which a rapid increase in temperature occurs and the final set when the highest temperature is reached.

Recent theories of the reactions between the calcium silicates and water, and other matters relating to the hardening of cement pastes, are reviewed. The reactions are of hydrolysis and hydration, both types of reactions associated with most of the constituents occurring simultaneously, but, as it is important to distinguish them, they are treated separately. The exposition of the water reaction in cement pastes is extended to such reactions in the presence of CaO, Al_2O_3, and Fe_2O_3. Although the existence of calcium sulpho-aluminate and calcium chloraluminate has long been known, it is only during the past fifteen years that other complex aluminate and ferrite salts have been detected, and those of interest to cement chemists are considered.

The book concludes with a brief consideration of the effect of external conditions on cement pastes (in particular the effect of sulphates, of aggregates that are not chemically inert, and of pozzolanas) and some procedures for testing the quality of cement. Throughout the book the author is careful to present various theoretical, and often conflicting, points of view, and generally leaves it to the reader to adjudicate. The extensive bibliographies given at the end of each chapter guide the reader to the voluminous literature of the subject.

Cement Production in Germany.

IN a recent number of "Die Bauwirtschaft," the production of cement in the month of October, 1947, in the western zones of Germany is given as 277,741 tons, compared with 221,429 tons in October, 1946. The average monthly production in 1946 was 194,325 tons which is about one-third of the average monthly production of 580,166 tons in this part of Germany in 1936.

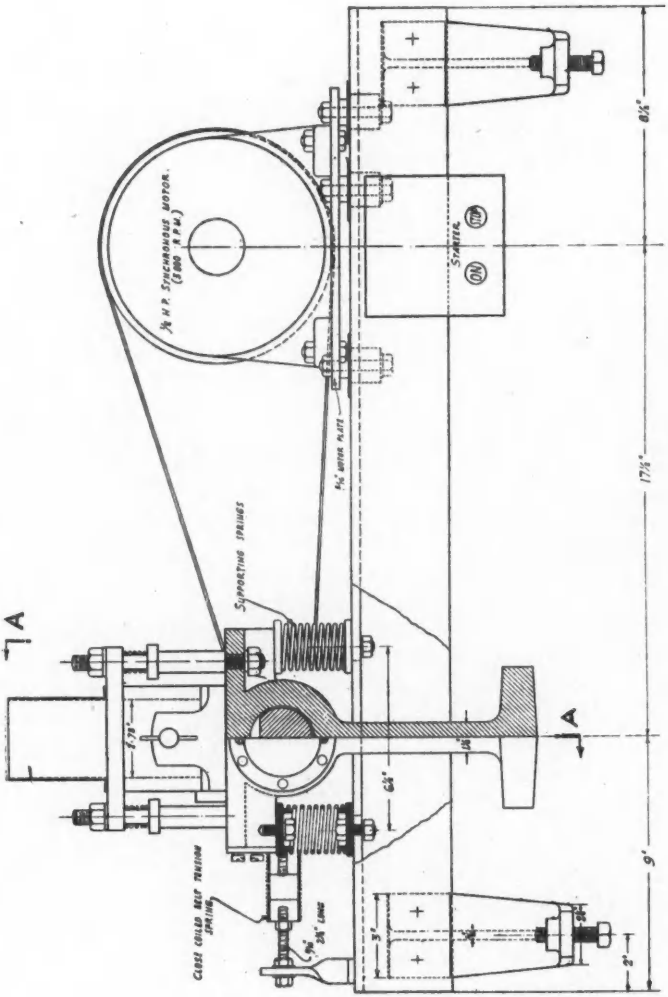

Fig. 2.—Machine for Compacting Mortar Cubes *(see opposite page).*

A Machine for Compacting Mortar Test-Cubes.

IN our number for March, 1948 (page 36), reference is made to a new machine for making cubes for the compressive test of cement mortar in connection with British Standards Nos. 12, 146, 915 and 1370 (1947). This machine is shown in the accompanying illustrations, which are reproduced by permission of the British Standards Institution from which copies of the drawings and a complete specification for a machine complying with the requirements of the British standard for compacting mortar cubes for compressive-strength tests can be obtained (reference No. P.D. 572. Price, £1.)

The machine comprises a hopper over a cube mould, the mould being clamped to a plate to which the vibrating gear, a solid eccentric shaft, and a balance weight, are attached. These parts are mounted on springs fixed to a table, on which is an electric motor. The principal dimensions and arrangement of the parts

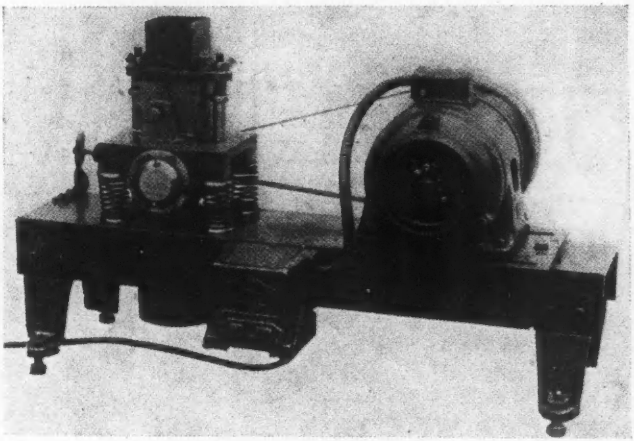

Fig. 1.—Machine for Compacting Mortar Cubes.

are shown in *Figs.* 2 and 3. The weight of the machine on its supporting springs, excluding the solid eccentric shaft but including the mould, mould clamp, cube, and hopper, is about 64 lb. The out-of-balance moment of the eccentric shaft is about 0·14 in.-lb. and the normal speed of the shaft is 12,000 revolutions per minute.

The top plate carrying the clamp for securing the mould, the balance weight, and the bearing housings are of cast steel and may be separate parts or a single casting. The driving-end bearing for the eccentric shaft is a roller journal bearing. The bearing at the other end of the shaft is a single-row ball bearing. Bearings with synthetic-resin cages are preferred. The four supporting springs are made of $\frac{1}{8}$ in. diameter wire, the outside diameter of each spring being $1\frac{3}{4}$ in., and the overall length in an uncompressed state $3\frac{3}{4}$ in. There are $10\frac{1}{2}$ coils, giving eight effective coils.

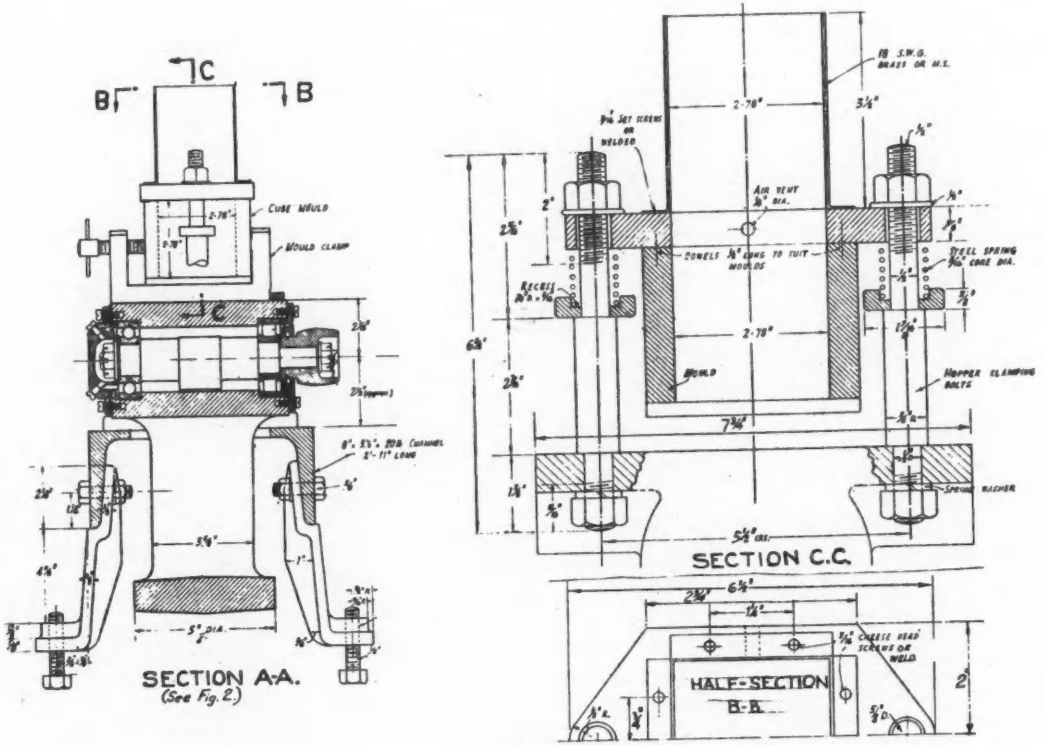
B
C
B
CUBE MOULD
MOULD CLAMP
2·78"
2·78"
2½"
2½" (approx.)
8" × 5½" × 20lb CHANNEL
2'-11" LONG
2½"
1½"
4½"
3¼"
1"
5" DIA.
SECTION A-A.
(See Fig. 2.)
16 S.W.G. BRASS OR M.S.
2·78"
3¼"
⅛" SET SCREW OR WELDED
AIR VENT ⅛" DIA.
2"
2½"
DOWELS ⅜" LONG TO SUIT MOULDS
STEEL SPRING ⅜" CORE DIA.
RECESS ⅜" × ⅜"
2·78"
MOULD
6½"
2½"
HOPPER CLAMPING BOLTS
7¾"
1⅛"
⅝"
SPRING WASHER
5¼" CRS.
SECTION C.C.
6½"
2½"
1¼"
⅝" CHEESE HEAD SCREWS OR WELD
HALF-SECTION
B-A
2"
⅜" R.
⅜"
⅝" D.

Fig. 3.

The driving pulley is 2½ in. in diameter and is attached to the end of the eccentric shaft ; it has a crowned face without flanges. The drive is by an endless belt, 1 in. wide and $\frac{1}{32}$ in. thick, made from close-woven cotton and tensioned by a spring to prevent slipping, thus dispensing with belt dressing. The machine rotates in a clockwise direction when viewed from the side on which the driving pulley is fixed. The speed of the shaft is checked periodically by a stroboscope or direct revolution counter.

The electric motor is synchronised-speed machine of ½ h.p. running at 3,000 revolutions a minute and fitted with a crown pulley of a diameter to give the required speed of the eccentric shaft. The motor is equipped with switchgear that enables the specified speed to be attained quickly and to operate at that speed for the specified period of vibration.

The complete machine, including the mould, mould clamp, cube, and hopper, is balanced by placing the shaft between centres, the correct balance being obtained by decreasing or increasing the mass of the balance weight, by boring holes or machining, or by lead filling, whichever is necessary. The centre of gravity of the complete machine thereby coincides with the centre of the eccentric shaft or within 1 in. below it. The machine is considered to be satisfactory for service if it has worked continuously for 24 hours at the normal rate of 12,000 r.p.m., without developing a fault and without undue rise of temperature of the bearings. This test, which is made when the machine is finally assembled, is made with the mould, mould-clamp, cube and hopper in position.

The revolving eccentric imparts an equal circular motion to all parts of the machine and mould, the motion being equivalent to equal vertical and horizontal simple harmonic vibrations 90 deg. out of phase. The slowest running speed of the machine is well above its natural frequency on the supporting springs, so that the amplitude of the vibration is independent of the speed.

The parts of the mould are held positively together during the filling of the mould and on removal of the filled mould from the machine. In assembling the moulds, the joints between the halves are covered with a thin film of petroleum jelly and a similar coating is applied between the contact surfaces of the bottom of the mould and the base plate so that no water escapes during vibration. The interior faces of the mould are treated with a thin coating of mould oil. The mould is then placed on the table of the machine and firmly held in position by the clamp. A hopper is securely attached to the top of the mould and is not removed until completion of the vibration.

Immediately after mixing in accordance with the requirements of the British standard, the whole of the mortar is placed in the hopper and is then compacted by vibration for two minutes at the specified speed. The cubes are kept at a temperature of 61 deg. in an atmosphere of at least 90 per cent. relative humidity for 24 hours after completion of vibration, when they are removed from the moulds and immediately submerged in clean water and kept there until just prior to being tested.

Research on Hydrolysis in Cement.

IN a paper read before the 20th Congress of Industrial Chemistry in Paris and published in a recent number of " Chimie et Industrie," Mr. A. Rebuffat reviews and carries further his work on the testing and analysis of cement, with particular reference to hydrolysis. The author expresses the view that the hydrolysis number in cement dispersions constitutes an additional characteristic of quality which gives further insight into the structure and composition of cements.

In 1934 he had noted that the ferrous oxide (FeO) in Portland cements in relation to the total ferric oxide (Fe_2O_3) was appreciable, and that there were often traces of oxidation from the surface inwards. It was possible to reduce the oxides with hydrogen without much change in physical properties, and he concluded that the iron was combined as silicate. Slag clinker and slag cement do not behave in this way. If the iron is combined with silica (SiO_2) the celite is not hydrolysable, in which case it should be possible, in aqueous dispersion, to recover the original compound. As the use of saccharified water was open to criticism the author first used brominated water which, when freshly prepared, dissolves the free lime but does not affect the lime salts. By treating very finely powdered cement with brominated water a liquid portion, and a residue which could be washed and dried, were obtained. However, the use of brominated water was not quite satisfactory and a new method was tried.

To 4 litres of carefully degasified and neutralised distilled water were added 2·5 g. of powdered cement and 2 cc. of phenolphthalein. When hydrolysis began hydrochloric acid N.10 was used as a neutraliser. The number of cubic centimetres used corresponds with the maximum amount of basic substance set free, and when reduced to a percentage gives an hydrolysis number. In the case of Portland cements the acid dissolves only the bases set free by hydrolysis ; the hydrolysis number is independent of the kind of acid used—sulphuric, hydrobromic, or organic— and, while these conditions of test are quite convenient, they may be varied. Heating naturally accelerates the action which, at 80 deg. C., requires about 50 hours compared with 100 hours without heating. These times vary with different types of cement. The samples must be of uniform fineness. In the case of pozzolana cements sulphuric anhydride (SO_3) is found in the liquid portion, together with nearly all the magnesia (MgO). The alkalis are found partly in the liquid and partly in the sludge. The alkalis and the magnesia are neutralised by the acid (see *Table* 1). The hydrolysis numbers of pozzolana cements are always similar to those of good Portland cements, and the ratio of free lime to total lime is about 0·91. For slag cements the hydrolysis numbers are generally smaller, the ratio of free lime to total lime is lower (about 0·85), and nearly all the magnesia and the sulphuric anhydride are found in the liquor while the sludge or residue contains any alkali that may have been originally present.

The amount of silica in the liquors is always much less than would be required if all the lime set free by hydrolysis were combined in the tricalcic silicate. In

Table II are given the amounts (in percentages) of silica, lime, and alumina in the liquors of the cements in *Table* I.

TABLE I

PERCENTAGE COMPOSITION AND HYDROLYSIS NUMBERS OF VARIOUS CLINKERS AND CEMENTS.

	Portland cements			Pozzo-lana cement	Slag cement	Iron cement
Specimen	I	II	III	IV	V	VI
Loss on ignition	0·73	0·38	0·26	0·34	0·54	—
SiO_2	21·93	22·70	23·70	22·23	23·23	18·80
Al_2O_3	5·73	5·49	5·24	3·28	5·41	6·05
Fe_2O_3	3·60	3·01	2·31	2·52	3·22	9·40
CaO	68·66	67·00	67·40	65·34	61·30	63·20
MgO	—	—	—	1·42	3·76	0·95
SO_3	—	—	—	1·30	1·53	—
Alkali (as Na_2O)	—	—	—	2·34	—	—
Mn_3O_4	—	—	—	—	0·18	—
Total	100·65	98·58	98·91	98·90	99·17	98·40
Hydrolysis No.	61·10	60·10	61·50	61·00	56·10	51·30
Free lime	61·08	60·20	61·40	59·00	52·00	48·86

The specimens I to V are Italian cements ; VI is a cement prepared by Professor Ferrari.

It is interesting to note the almost complete absence of alumina. According to Mr. K. Koyanagi, who found amounts of alumina similar to those in *Table* II, the alumina would not remain in the gel state because the increasing amount of lime in the liquor would combine with it to form aluminate ; this is not perhaps of great importance.

TABLE II

Specimen	I	II	III	IV	V	VI
Silica	14·89	11·55	14·23	13·47	12·60	12·80
Lime	61·08	60·20	61·40	59·00	52·00	48·86
Alumina	0·39	0·25	0·24	0·00	0·00	trace

It is probably of greater moment to study the cement powder immersed in a solution of xylene in which it appears to consist for the most part of colourless fragments, some of which are optically active, and of other fragments composed of two distinct parts one of which is brownish-yellow in colour and the other almost colourless. The brownish particles are not isolated ; sometimes they adhere to a single clear or colourless fragment, but nearly always they are squeezed between several others of varying crystal form. The effect, for example, of prolonged grinding crushes the crystals without detaching the celite therefrom.

Residues kept in sealed tubes under water with an indicator show at first a little coloration which may soon disappear, and which is more marked with slag

cement or clinkers the residues of which have a reddish tint. In other cases residues were kept under water or dry for some years without any appreciable change being noticeable. When hydrolysis is complete the residues do not change and contain about 40 per cent. of the original silica content, all the iron and alumina, and 9 per cent. or more of the lime. But they all show a loss on heating which is quite appreciable and characteristic for each type of cement. If the samples are dried for some time in air at 100 deg. C., this loss can always be noted ; the loss increases to some extent with rise in temperature, and if then left to cool the residues re-absorb the moisture lost.

Although the samples are very slightly resistant to acids even when the acids are diluted and used cold, a tepid solution of 50 per cent. potash appears to have little effect. The samples are dissolved by sodium carbonate, with the formation of red hydrated ferric oxide (Fe_2O_3) ; 2 per cent. sodium bisulphite appears to have no solvent action. If the cement clinker contains ferrous oxide, even if brominated water is used, the ferrous oxide is invariably found unchanged in the residue. If the clinker is immersed in a solution of an ammonium salt, part of the lime is replaced and, by subsequent treatment with 10 per cent. calcium chloride, the evolution of ammonia is fairly vigorous. If the clinker is now again treated with ammonium salt solution there is again a replacement of lime. The residues appear to have zeolitic form and properties.

In a drop of water or other neutral liquid under the microscope the residues appear to consist of two distinct parts, one brownish-yellow and the other colourless, the latter generally surrounding the former. The coloured nuclei (celite) keep their original forms. If a trace of Congo red is added to the water, the clear colourless parts become rose-tinted. If gels of silica and alumina are now prepared and mixed, the mixture has properties very different from the residues, for example, in being less rapidly attacked by acid ; also, while both absorb ammonia vapours, the gel mixture shows much greater absorption of heavier vapours (molecular weight over 50, such as benzol). With the heavier vapours, indeed, there is no absorption by the residues. Moreover, although the residues must be immersed in water or other liquid for microscopical examination, this is not necessary for the gel mixture. It is tentatively concluded that the clear colourless part of the residues differs definitely from a gel mixture, and is regarded as having a structure nearer to that of a zeolite than to that of a permutite, a conclusion that the author proposes to check by spectrographic tests.

Since the colourless part of the residue, as also natural zeolites, may be regarded as intermediate between colloids and crystalloids, it was expected that the two phases could be separated, as was proved to be the case by repeatedly treating the residue with a warm (40 deg. C.) N.50 caustic soda solution. Almost always the very small particles of quartz or silicate were removed in the first washing. From the point of view of dispersion the residues could be divided into the following three groups.

Group C.A.—After several washings the zeolitic part is completely dispersed ; the microscope shows the celite to be intact and, although hydrated, not

colloidal. The forms of the original celite, or portions of the original cement from which the crystals have been removed by hydrolysis and dispersion, are recognised. In the celite fraction are silica, iron, and lime, but no alumina ; the alkaline liquor contains silica, alumina and lime. This group comprises Portland and pozzolana cements.

Group C.B.—This is slag cement which differs in structure from ordinary Portland cement. In the unhydrolysed cement two celitic forms may be observed, one brownish-yellow and the other red, sometimes together and sometimes separated. Only the brownish-yellow part appears to be the same as that in Portland cement. After hydrolysis the red portion disappears ; also, after three or four washings, the colourless part appears to be dispersed. If treatment with soda solution is continued, however, some alumina still passes, although slowly, and to accelerate this action the temperature must be raised to 60 to 70 deg. C. The celitic fraction finally contains only silica, iron, and lime. This indicates fairly clearly that in cements of this type the alumina is combined in two different forms, with different properties, and thus Brownmillerite ($4CaO.Al_2O_3.Fe_2O_3$) may be present. This is not the case with ordinary Portland cement. There are conflicting views about the hydration of Brownmillerite. According to some the compound may be divided into hydraulically inactive monocalcium ferrite and tricalcium aluminate ; or bicalcium may be present as in Portland cement, at least in the decomposition residues. Consideration of the various possible reactions indicates further that if Portland cement is re-heated to 700 to 750 deg. C., the free lime is increased, whereas the contrary is the case with slag cement. The decrease in the case of slag cement must be due to the formation of aluminates, and confirms that there is little or no free aluminate in Portland cement. Although further research in this direction is needed, it may be supposed that, if the celitic fraction is surrounded or enveloped by the zeolitic fraction, reaction or decomposition in the former is retarded or blocked by the latter. The question of intermediate products further complicates the picture.

Group C.C.—This is represented by cement No. VI in *Table* I. There is little or no clear colourless substance. After two washes with the alkaline solution there is no further removal ; but the celitic fraction still contains half the alumina of the original cement and invariably some silica. Omitting specimen No. 1, (a Portland cement) the residues of hydrolysis of the cements in *Table* I have the analyses given in *Table* III.

TABLE III

Specimen No.	II	III	IV	V		VI
				initial	final	
Loss on ignition	13.10	15·85	18·28	16·45	17·30	10·90
Silica	17·80	14·40	19·73	16·00	17·33	10·50
Ferric oxide (Fe_2O_3)	41·00	41·50	32·15	33·20	36·88	32·57
Alumina	—	—	—	4·10	—	9·98
Lime	25·40	26·40	23·22	28·90	26·70	33·80
Magnesia	—	—	—	—	—	—
$\frac{Fe_2O_3}{CaO}$	1·61	1·57	1·38	1·34	1·41	0·98

In determining the loss on ignition of a freshly prepared cement an increase rather than a decrease in the ratio of ferric oxide to lime is found. Due to the presence of iron oxides, this may be of little account with low-iron cements, but is important with isolated celite containing up to 40 per cent. of iron oxides. Since the ratio is 2·84 for metaferrite and 1·42 for dicalcium ferrite it may be concluded that in cements (or residues) represented by specimens Nos. II, III, and IV the ratio is about 2. In the case of sample No. VI the permanganate test is at first almost negative, and the celite is apparently not hydrolysed. Reckoning that all the alumina is combined as Brownmillerite taking 15·64 per cent. of the ferric oxide and 21·9 per cent. of the lime, there is left 16·93 per cent. of the ferric oxide and 11·9 per cent. of lime, so that the ratio of ferric oxide iron to lime is still about the same. This is a solid solution. However, the composition of specimen No. VI appears to be somewhat abnormal and its properties are not yet fully known. In the case of specimen No. V there is an initial and a final stage, the first being distinguished by dispersion of the zeolitic fraction; but equilibrium is eventually attained and there appears to be a mixture corresponding to 1 part of Brownmillerite to 3 parts of dicalcium ferrite.

The question may next be considered whether the silica found in all celites is or is not an impurity or a formation due to hydrolysis. The fundamental and well-known characteristic of ferrite is that it can be decomposed by a reducing agent at sufficiently high temperature, generally with CO as the reducing gas. The author, however, preferred to use hydrogen and an electrically heated reduction tube (750 deg. C.) capable of testing several samples at the same time. Losses of oxygen were determined with permanganate and results are given in the form of a graph showing variation with time of the ratio of oxygen to iron up to 60 hours. The author does not think that particle size is an important factor, but that the important factor is that, after 60 hours, the loss of oxygen is much less than that contained in the sesquioxide of the clinker and the curves tend to become asymptotic. Also, after a certain period, say 40 hours, the cements are liable to become oxidised (or peroxidised) at a relatively rapid rate. This appears to be due to the fact that the metallic iron formed by reduction is in a very finely divided, indeed pyrophoric, condition. It is concluded that the celite does not follow the known simple laws for bicalcium ferrite and Brownmillerite owing to its silica content, and that the silica is not a fortuitous impurity but actually a part of the celite.

After discussing the significance of some of the changes of colour noted, the author considers the zeolitic part of the hydrolysed residues. This is obtained by evaporating the alkaline liquor. Three groups (Z.A., Z.B., and Z.C.) are obtained, corresponding respectively to:

Z.A.—3 $SiO_2.Al_2O_3.CaO$	.. 3 mol. water	(Scolesite).
Z.B.—4 $SiO_2.Al_2O_3.CaO$	.. 6 „ „	(Gmelinite and Chabazite).
Z.C.—5 $SiO_2.Al_2O_3.CaO$	.. 5 „ „	(Philipsite).

The importance of these groups need not be over-rated, and the fact that in hydrating cements one or the other zeolite is formed matters little. What does matter is the knowledge that zeolitic substances are formed at all. The author

intends to study further the origin of these zeolites in Portland cement. X-ray examination has revealed that they are highly symmetrical crystalline substances which are not present in the original cement but originate from the reaction of an alumino-silicate with water. This reaction is rapid and the original crystalline structure is changed. It may be that absorption of water precedes the elimination of lime, and the whole problem is complex. Some results of microscopic examination are briefly noted by the author, but the main point appears to be the envelopment of the zeolite by celite which eventually inhibits further action of water on the zeolite. Somewhat similar phenomena may be observed with other minerals. Some micro-photographs of residues are given by the author and include zeolitic and celitic formations.

The general conclusion is that the setting of cements is nothing else than the formation of zeolitic substances under special conditions. If, while these are forming, the particles are in contact they combine and form a continuous layer in which are held fast the products of hydrolysis ; but if, on the other hand, the particles are separated the zeolite may still form but the cement does not set. Setting is dependent on alumina content, but this is also subject to qualification as the alumina exists in various forms some of which are not hydraulic. The rate of setting is certainly connected with the ratio between the amounts of alumino-silicates and other compounds present, which act as diluents whether hydrolysable or not. Generally a high alumino-silicate content or ratio would mean rapid setting. If alkali is present it is probable that the alumino-silicates are alkaline, and on heating there will be formed a quaternary compound from which originates a zeolite of the type of clinker represented by specimen No. IV in *Table* I (Z.B. group). Magnesia is generally present, and if in small percentages it will probably have replaced some lime without serious effect ; but if the magnesia increases beyond a certain limit there may possibly be formed some compounds which become hydrated slowly and may cause a certain amount of expansion.

The author also considers the effect of gypsum. As already stated, sulphuric acid may be used instead of hydrochloric acid for determining the hydrolysis number. The same number is obtained, the time of operation does not appear to vary, the residue is the same, and, if the ratio of powder to water is increased, there is no noticeable difference. The effect of gypsum seems to be purely physical. Gypsum is much softer than the clinker, and in the grinding it becomes extremely fine. When wet it appears to form a more or less protective film on the other particles which prevents the water being absorbed too rapidly. In regard to the action of air, carbon dioxide can decompose free ferrites with the formation of free aluminate. This might explain the fact that the setting of slow-setting cements is accelerated on exposure to air through the decomposition, for example, of Brownmillerite and the formation of aluminates.

The foregoing is mainly an exposition of certain facts or phenomena which can be verified and refers to clinkers normally burnt at about 1450 deg. C. It is obvious from this study that one cement differs from another, an important factor being the composition of the raw materials.

Spectrographic Analysis of Portland Cement.

THE following description of a spectrographic method for the determination of the constituent elements of Portland cement, particularly the minor elements that may contribute favourable or unfavourable properties to concrete, is from the *Technical News Bulletin* of the United States National Bureau of Standards and includes more details than are given in the note on this subject in our number for March, 1948. The usual chemical methods of analysis of Portland cement for minor elements take time and are subject to considerable error, particularly in the determination of the alkali elements. This method, which grew out of earlier investigations applied specifically to the determination of sodium, potassium, and lithium, was extended by Mr. A. W. Helz and Mr. B. F. Scribner to the determination of those constituents of Portland cement susceptible of easy spectrographic determination.

The principal problem involved in spectrographic analysis is to excite the characteristic spectra of the elements in the sample in a reproducible manner. This was accomplished in the analysis of Portland cement by the new method of forming a compressed pellet of the cement mixed with a binder of graphite powders, a reference material of cobalt oxide, and a buffer of potassium nitrate. The pellet and a graphite rod serve as electrodes between which an intermittent-arc discharge is passed. The light from the arc is then observed with a spectrograph and the photographed spectrum is measured for the characteristic lines of the element to be determined. Quantitative determinations are based on comparison with standard samples of cements having compositions determined by chemical methods.

In the sample mixture the graphite serves a dual purpose, namely, to bind the material together when pressed into the required pellet $\frac{1}{4}$ in. in diameter and $\frac{1}{8}$ in. thick, and to conduct electricity through the electrodes. The cobalt oxide provides a reference element in fixed concentration in the sample; the intensities of the spectral lines of the minor elements in the cement are measured relative to the intensities of selected cobalt lines. The addition of a known excess of potassium nitrate overcomes effects on the spectra caused by variations in the concentrations of the alkaline elements in the cement.

The method provides for the quantitative determination of the following constituents, which are reported as a concentration of their oxides: Aluminium, iron, magnesium, sodium, potassium, manganese, and vitanium. In addition, suitable spectral lines are given for the detection of lithium, chromium, strontium, and zirconium.

An operator can analyse eight cement samples in duplicate for seven elements, a total of 112 determinations, in eight hours. The time required for the equivalent chemical analysis would be several days. Furthermore, the method is sufficiently accurate for control work and is believed to be advantageous for applications in which a considerable volume of testing is involved.

Automatic Controls in Lime Manufacture.

A NEW lime plant built in Virginia, U.S.A., for the National Gypsum Co., has some automatic controls which are said to be new to the industry. The limestone used has a $CaCO_3$ content of 98 per cent., less than 1 per cent. of magnesium carbonate and very small quantities of iron, alumina, silica and phosphorus. The ultimate capacity of the plant is 600 tons of pebble lime per day.

The stone calcined in two 8 ft. by 10 ft. by 300 ft. rotary kilns fitted with 8 ft. 6 in. tubular rotary coolers. The kilns slope $\frac{1}{2}$ in. per foot, and their speed can be varied according to the rate of feed. The enlarged calcining zone is 100 ft. long. From the discharge end the first 10 ft. of the kiln is lined with high-heat-duty 9 in. fireclay bricks, followed by 60 ft. of 70 per cent. alumina bricks 9 in. thick without insulation, 30 ft. 6 in. of 60 per cent. alumina bricks 6 in. thick insulated with $2\frac{1}{2}$ in. magnesium blocks and $\frac{1}{4}$ in. of cement mortar on each side of the blocks. The enlarged calcining zone tapers to the smaller diameter over a distance of 20 ft., and this part is lined with 60 per cent. alumina bricks. The rest of the kiln to within 10 ft. of the feed end is lined with 6 in. abrasion-resisting bricks and $2\frac{1}{2}$ in. insulating magnesia blocks and $\frac{1}{2}$ in. of insulating mortar. The final 10 ft. is lined with 9 in. bricks without insulation.

The kilns are controlled from an instrument panel on the kiln operating floor. The instruments are electronic devices that control, through pneumatic controllers, the various adjustments. At present each adjustment is made separately, but the controllers are so arranged that they can automatically make adjustments required to conform with a change made in one of the firing variables. For example, should the primary air flow be increased in order to attain more heat, the coal feed rate, the secondary air flow and the induced draught would automatically change. The instruments include (*a*) a fluid meter to record the primary-air flow and the coal-air mixture temperature; (*b*) a fluid meter to record the secondary-air flow; (*c*) recorder to indicate the kiln temperature at the hood, and the kiln speed; (*d*) recorder to indicate the kiln temperatures at each of the third points, as measured by thermocouples; (*e*) a recorder to indicate the kiln-outlet temperature and the induced-draught inlet temperature; (*f*) a recorder to show the oxygen content of the gases leaving the kiln; and (*g*) a multi-pointer gauge to indicate the primary-air differential, mill differential, secondary-air pressure, induced-draught and hood draught.

The control equipment includes partly automatic selector valves for induced draught, primary air, raw-coal feed, secondary air, and tempering air, and controllers for primary air—secondary air ratio, the pulverizer feeder, kiln-hood draughts, coal-air mixture temperature, and the induced draught inlet temperature. Accessory instruments are ammeters for the kiln drive, stone feeder drive, induced-draught fan motor, cooler-fan motor and pulverizer drive; push-button switches and signal lights, and an air-failure alarm system.

The primary air damper is regulated by remote manual control according to observations of the burner and temperature readings on the panel board.

The ratio of coal feed to primary air is maintained by regulating the feeder knife by the pulverizer-feeder controller which takes impulses from a primary-air-flow pitot tube and regulates the coal feed to maintain a proportional pulverizer differential.

The secondary-air damper is regulated by the fuel-air ratio controller, which balances the primary-air flow against that for secondary air. Readjustment of this controller is done manually according to observation of the oxygen recorder in order to maintain the desired quantity of excess air.

The tempering-air damper for the primary-air fan is regulated by the temperature-recorder controller to keep the temperature of the coal-air mixture constant when it leaves the pulverizer. Induced-draught dampers are adjusted by the draught controller to maintain a steady hood draught. It is desired not to exceed a temperature of 700 deg. F. for the exit gases as they enter the induced-draught fans in order to protect the fans. Temperatures as indicated by thermocouples spaced at 100 ft. and 200 ft. inside the kilns serve as indicators of the quality of the lime as measured by the presence of core.

The Properties of Portland Cement.

IN his presidential address to the Cement & Concrete Association of Australia, Mr. S. S. B. Purves suggested that further investigations be made on the effect of fine grinding of cement on the durability of concrete, and that the question of durability be considered as of more importance than the early release of shuttering. The need for durable concrete, particularly concrete surfaces, justified the time and cost required to make long-period tests of fine and coarse cements of the same composition. He thought, also, that too much importance was placed on the strength of cement in relation to other properties, particularly as Portland cement already possessed greater strength than was necessary for ordinary structural requirements. Recent reports on the cement industry in Germany were, he said, a striking example of the excellent concrete that could be made with cement made with what we would consider to be a lack of refinement and control in manufacture.

Cement Plant for India.

THE United Provinces Government has placed a contract with Vickers-Armstrongs, Ltd., for the cement-making machinery and electrical equipment for a cement plant with a daily capacity of 700 tons near Markundi in the Mirzapur district. The value of this order is about £870,000. The cement will be used primarily for the construction of the Rihand dam. The machinery, including two 300 ft. kilns, will be manufactured at Barrow-in-Furness.

Cement Production in Poland.

IN the year 1947 the Polish cement industry produced 1,450,000 tons of Portland cement. It is anticipated that the pre-war rate of production, namely, 1,700,000 tons, will be reached in the year 1948.

Some Recent Foreign Specifications for Cement.

IN the following are given particulars of revised standard specifications and provisional specifications for cement which have been published during the past few years in Brazil, Bulgaria, Portugal and Uruguay. Some observations are given on page 67 on the magnesia content permitted by some standards. The new Czechoslovakian standards, are given in our number for January 1948. New standards published recently in Ireland (Eire), France, and Poland, are given in various numbers of this journal for 1947.

Brazilian Standards for Portland Cement.

The current Brazilian standards for Portland cement are those for ordinary Portland cement (No. EB-1 revised in 1937 and superseding the edition of 1934), and for rapid-hardening Portland cement (No. EB-2 published in 1940). The mechanical tests are described in No. MB-1 published in 1937 and the methods of chemical analysis are described in No. MB-11 published in 1940.

No hydraulic modulus is specified, but for ordinary and rapid-hardening Portland cements the maximum amount of sulphuric anhydride is 2·5 per cent. ($\pm$ 0·15 per cent. compared with $\pm$ 0·1 per cent. in the specification of 1934), the insoluble residue permitted is 0·85 per cent. ($\pm$ 0·15 per cent.), and the loss on ignition must not exceed 4 per cent. ($\pm$ 0·3 per cent. compared with $\pm$ 0·25 per cent.). The maximum amount of manganese oxide is 6 per cent. ($\pm$ 0·4 per cent.) for ordinary Portland cement and 5 per cent. ($\pm$ 0·3 per cent.) for rapid-hardening Portland cement. In rapid-hardening Portland cement the greatest amount of foreign matter permitted is 1 per cent. No final setting time is specified, but the minimum initial setting time is one hour. The maximum expansion as measured by the Le Chatelier test is 10 mm. for ordinary Portland cement and 3 mm. for rapid-hardening Portland cement. The Vicat test for the setting-time and the Le Chatelier test are described in Standard No. MB-1.

The fineness is measured by the residue, which must not exceed 15 per cent. for ordinary Portland cement, on a sieve having an aperture of 0·075 mm. (0·003 in.). The residue for rapid-hardening Portland cement must not exceed 6 per cent., but for this type of cement a turbidimeter test, which is not described, is permitted, and the specific surface must not be less than 1900 sq. cm. per gramme.

No tensile test is specified, but compression tests on cylinders of 1 : 3 mortar, 50 mm. (1·97 in.) in diameter and 100 mm. (3·94 in.) long, are described in No. MB-1. For ordinary Portland cement the compressive strength must not be less than 1139 lb. per square inch at 3 days, 2134 lb. per square inch at 7 days, and 3556 lb. per square inch at 28 days. For rapid-hardening Portland cement the minimum compressive strengths are 1565 lb. per square inch at 1 day, 3129 lb. per square inch at 3 days, and 4409 lb. per square inch at 7 days.

Tests for determination of the loss on ignition, the insoluble residue, and the amounts of silica (SiO_2), iron oxides (Fe_2O_3 and FeO), lime (CaO), magnesium

oxide (MgO), and sulphuric anhydride (SO_3) are described in No. MB-11, 1940. Methods of determining the amounts of the secondary components are also given. These components comprise manganic oxide (Mn_3O_4), phosphoric anhydride (P_2O_5), and sulphur (S). Titrimetric and colorimetric methods are described for determining the titanium oxide (TiO_2), and alcohol-glycerine and alcohol-phenol methods of determining the oxide and hydroxide of the free lime are described. It is specified that if chromium, vanadium, or zirconium is present the amounts should be expressed in terms of the respective oxides, Cr_2O_3, V_2O_5, or ZrO_2. The amount of alumina (Al_2O_3) is obtained by deducting from the total amount of oxides, which is determined by a specified test, the sum of the amounts of Fe_2O_3, TiO_2, Mn_3O_4, P_2O_5, Cr_2O_3, ZrO_2, and V_2O_5.

Bulgarian Standard Specification for Portland Cement.

The latest Bulgarian standard specification for Portland cement was published in 1941 and differs from the previous (1937) edition in a few particulars. The amount of lime as expressed by the ratio $\frac{CaO}{SiO_2 + Al_2O_3 + Fe_2O_3}$ must not be less than 1·7, the amount of magnesium oxide (MgO) must not exceed 5 per cent., the loss on ignition must not exceed 5 per cent., and the amount of foreign matter must not exceed 3 per cent. These requirements are unaltered, but the maximum permissible amount of sulphur trioxide (SO_3) is increased from 2·5 per cent. to 3 per cent. The setting times are still not less than one hour and not more than 12 hours for the initial and final set respectively. The fineness, which is also unaltered, must be such that the residues on sieves having 178 and 76 meshes per inch do not exceed 25 per cent. and 2 per cent. respectively.

The minimum tensile strengths or ordinary Portland cement mortar are unaltered and are 256 lb. per square inch at 7 days and 356 lb. per square inch at 28 days with ordinary curing or 427 lb. per square inch with special curing. The corresponding compressive strengths are, however, increased to 2845 lb., 4267 lb., and 5689 lb. per square inch respectively. The strengths of high-strength rapid-hardening Portland cement have been reduced by about 10 per cent. and are now as follows: tensile strength at 3 days, 356 lb. per square inch, and at 28 days, 427 lb. per square inch for ordinary curing and 569 lb. per square inch for special curing; compressive strength at 3 days, 3560 lb. per square inch, and at 28 days, 5689 lb. per square inch for ordinary curing and 7112 lb. per square inch for special curing. Ordinary curing is 24 hours in water and the remaining time in air at 17 deg. to 20 deg. C. Special curing is 24 hours in water followed by six days in air at 17 deg. to 20 deg. C. and 21 days in water at 17 deg. to 20 deg. C.

Low-Heat Portland Cement in Portugal.

A provisional specification recently issued by the Portuguese Government for the manufacture and use of a Portland cement with a low heat of hydration contains the following requirements.

The chemical composition must be such that the following proportions are not exceeded: Magnesium oxide (MgO), 5 per cent.; sulphur trioxide (sulphuric

anhydride), (SO_3), 2 per cent.; ferrous oxide (FeO), 6·5 per cent.; tricalcium-silicate ($3CaO.SiO_2$), 35 per cent.; and tricalcium-aluminate ($3CaO.Al_2O_3$), 7 per cent. The amount of bicalcium-silicate ($2CaO.SiO_2$) must be not less than 40 per cent. The loss on ignition must not exceed 2·3 per cent., and the insoluble residue must not exceed 0·75 per cent.; these percentages compare respectively with 3 per cent. and 1 per cent. in British Standard No. 1370 (1947), "Low Heat Portland Cement."* Direct comparison of the chemical requirements of the Portuguese specification with those of the British Standard are not possible except for magnesia and sulphuric anhydride, the maximum amounts of which are 4 per cent. and 2·75 per cent. respectively in B.S. No. 1370.

The percentages of tricalcium-silicate, bicalcium-silicate, and tricalcium-aluminate are calculated from the percentages of the various compounds in accordance with the following expressions:

$3CaO.SiO_2$: $4·07(CaO) - 7·60(SiO_2) - 6·72(Al_2O_3) - 1·43(FeO_3) - 2·85(SO_3)$.

$2CaO.SiO_2$: $2·87(SiO_2) - 0·754(3CaO.SiO_2)$.

$3CaO.Al_2O_3$: $2·65(Al_2O_3) - 1·69(Fe_2O_3)$.

The terms in parentheses are the percentages of the oxides expressed to the first place of decimals. The percentages of the tricalcium and bicalcium compounds are also approximated to the first place of decimals and are then expressed to the nearest whole number.

The fineness is expressed as the specific surface in square centimetres per gramme, and the average value must be not less than 1800 sq. cm., nor must the specific surface of any one sample be less than 1700 sq. cm. This degree of fineness compares with 3200 sq. cm. (minimum) required by B.S. No. 1370 when measured by an apparatus comprising a permeability cell, a manometer, and a flowmeter. In accordance with the Portuguese specification the specific surface is measured by a Wagner turbidimeter, in the operation of which a ray of light of constant intensity is passed through a sedimentation tank containing the sample of cement in suspension. The ray falls upon a photo-electric cell, thereby producing an electrical current which is measured by a milli-ammeter. The magnitude of the current is a measure of the fineness of the cement and serves as a basis for calculating the specific surface.

The maximum expansion by the Le Chatelier test is 4 mm. compared with 10 mm. according to B.S. No. 1370.

The initial setting time must be not less than 45 minutes and the final setting time not greater than 10 hours. The British Standard requirements are one hour and 10 hours respectively.

The crushing strengths of 1 : 3 mortar cubes after one day in air and 6 days in water must be not less than 200 kg. per square centimetre (2845 lb. per square inch) and, after one day in air and 27 days in water, 300 kg. per square centimetre (4267 lb. per square inch). The corresponding British Standard strengths are 1600 lb. and 3750 lb. per square inch respectively.

The tensile strength of 1 : 3 mortar briquettes cured under similar conditions

* See this journal for March, 1948.

to the cubes are 17 kg. per square centimetre (242 lb. per square inch) at 7 days and 21 kg. per square centimetre (299 lb. per square inch) at 28 days.

The heat of hydration at 7 days and 28 days is to be determined by the method described in Specification C-186-44T issued by the American Society for Testing Materials, but no limits are given in the Portuguese specification.

In an official report relating to this specification the means recommended for reducing the temperature of mass concrete are stated to include artificial cooling of the concrete, placing the concrete during cold weather, cooling the aggregates, restricting the amount of concrete placed at one time, reducing the proportion of cement, and the use of cement having a low-heat of hydration.

The report also states that the tricalcium-silicate and bicalcium-silicate are the compounds from which a hardened Portland cement derives the greater part of its strength, to which the tricalcium-silicate contributes the most. The bicalcium-silicate contributes little at early ages but its effect increases with age. The tricalcium-aluminate contributes considerably to the strength up to about 28 days but its effect diminishes, and may even become adverse, after one or two years. When the porportion of tricalcium-aluminate is high compared with the two silicates the heat of hydration is augmented, and the tricalcium-aluminate in a low-heat cement is therefore the least desirable compound. Thus a cement which contains a small amount of tricalcium-aluminate may have eventually a greater strength, may generate less heat, may have less tendency to crack, and may have a greater resistance to sulphate attack. The foregoing statements are based on the "Concrete Manual" issued by the United States Bureau of Reclamation.

In American types of low-heat cement the maximum proportions of tricalcium-silicate and tricalcium-aluminate are 35 per cent. and 7 per cent. respectively. Thus there is the necessity to increase the amount of bicalcium-silicate to not less than 40 per cent., and also to increase the amount of tetracalcium-alumina-ferrite ($4CaO.Al_2O_3.Fe_2O_3$), which reduces the rate at which strength is gained. A low rate of gaining strength is disadvantageous for concrete placed at low temperatures and with rapid methods of construction. Thus it is thought that a moderate-heat cement may be preferable, that is a cement in which the amount of silicate is the same as in ordinary Portland cement, but with the amount of tricalcium-aluminate raised from 7 per cent. (as in a true low-heat cement) to 8 per cent.

The foregoing notes are based on the Specification and accompanying report published in a recent number of "Cemento-Hormigon."

Uruguay.

The provisional specification for ordinary Portland cement, No. 20.P (1945), published by the Institute of Technical Standards of Uruguay, excludes special Portland cements such as rapid-hardening, low-heat, and sulphate-resisting cements. As in the specification issued in 1929, no requirements for fineness are specified and the maximum amounts of magnesia, MgO (4 per cent.), and insoluble residue (0·85 per cent.) are unaltered. The maximum amount of sulphuric anhydride is increased from 2 per cent. to 2.5 per cent., and the loss on ignition

is reduced from 4 per cent. to 3 per cent. The shortest time of initial set is increased from 35 to 45 minutes and the time for the final set must not exceed 10 hours, no minimum time now being specified. The test for expansion is made in an autoclave and the expansion must not exceed 5 per cent. As many laboratories are not yet equipped with the apparatus required for this test, the Le Chatelier test is provisionally acceptable. The tensile test is replaced by a compressive test, the minimum crushing strength at seven days being 2134 lb. per square inch.

Details of the methods to be employed for the chemical analysis of Portland cement are given in a separate Standard, No. 22.P (1945), and for the physical and mechanical tests in No. 21.P (1945).

The chemical and physical requirements for rapid-hardening Portland cement are given in Standard No. 41.P (1945) and are the same as those for ordinary Portland cement except that the amount of tricalcium-aluminate, as calculated by the expression 2.65 (percentage of Al_2O_3) — 1.69 (percentage of Fe_2O_3) must not exceed 15 per cent. The amount of foreign matter added must not exceed 1 per cent. The compressive resistance must be not less than 1565 lb. per square inch at 24 hours and 4409 lb. per square inch at seven days.

Magnesia in Cement.

THE report that the new Czechoslovakian specification for Portland cement permits a magnesia content of 6 per cent. may cause some surprise in view of the experience of late unsoundness due to high magnesia content. The subject is dealt with at length in Technologic Paper No. 102 of the United States Bureau of Standards (" Properties of Portland Cement having a High Magnesia Content," by P. H. Bates), but it is felt that this should be read with caution as it does not seem to take sufficient account of the effect of high magnesia content on later unsoundness and some of the statements in the paper do not seem to be in accord with practice. In order to avoid the troubles experienced in the United States due to late unsoundness resulting from a high magnesia content, the American standard specification now restricts the MgO content to 5 per cent. for cements of types Nos. I, II, and III, and to 4 per cent. for type No. V, and has introduced the autoclave test because it is thought that this will detect late unsoundness due to magnesia. Also, some American manufacturers air-quench the clinker in order further to reduce the effect of MgO. The British Standard limits the MgO content to 4 per cent., and cements made according to this Standard are not subject to late expansion. It therefore seems desirable that the MgO content should not exceed 4 per cent., that if it is between 4 per cent. and 5 per cent. the clinker should be air-quenched in a cooler of the Fuller type, and that if it exceeds 5 per cent. the raw material should not be used.

Distribution of Cement.

THE following announcement has been issued by the Ministry of Works.

The Ministry of Works has worked out, in consultation with the industries and distributing interests involved, a scheme for the distribution of cement during the summer of 1948. The object of the scheme is to ensure that Scotland, Wales, Northern Ireland, and each region in England receives a fair share of available supplies and that supply is fully adequate for the priority demands in each area. It is the intention of the Government to promote substantial exports of cement, so that great care must be exercised in the distribution and use of available supplies for home needs notwithstanding the reduced demands which should follow the restrictions imposed by the White Paper on Capital Investment in 1948. It will be necessary to ensure that priority work in each region has a first claim upon the available supplies. For this purpose the Ministry of Works intends to rely upon very close collaboration between their regional representatives and the manufacturing and distributing interests involved, who have given full assurances of co-operation with the department.

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STAFF required by Government of Ceylon for Cement Factory, Kankesanturai, in course of construction.

MANAGER. Salary £1,600 per annum fixed; appointment probably Autumn 1948; 10 years' agreement. Candidates, aged 40–45, must be qualified engineers with cement works management and preferably power plant (Diesel) experience and some chemical knowledge. Previous experience as manager or assistant manager in cement works also necessary. Knowledge of dry process, oil and coal fired kilns an advantage.

CHIEF ENGINEER. Salary £1,000 per annum fixed. Appointment probably December 1948; 5 years' agreement. Candidates, aged 40–45, should have good practical training in general mechanical engineering, and be familiar with chemical engineering. Should have sound practical training in cement works' operation and maintenance, including stone quarrying experience. In general should be capable of acting as manager if necessary. Should also have power station knowledge, as it will be necessary to interchange with Power Station Engineer.

CHIEF CHEMIST. Salary £900 per annum fixed. Appointment probably September 1948; 5 years' agreement. Candidates, aged 35–45, should have sound chemical training and be competent in organic analysis, with knowledge physics and, if possible, physical chemistry; must have practical cement works' experience and complete knowledge of uses of cement, as he may have to answer questions on this subject from clients and investigate complaints.

POWER STATION ENGINEER. Salary £750 per annum fixed. Appointment probably December 1948; 5 years' agreement. Candidates, aged 35–45, should have first-class practical experience of power station operation with particular knowledge of Diesel generating plant, and be familiar with electric motors, control, power, transmission, lighting. Should also have some cement works' experience, as it may be necessary to interchange with chief engineer.

In all the above appointments it would be an advantage for candidates to hold suitable degree and/or equivalent Institution membership.

CHIEF BURNER. Salary £650 per annum fixed. Appointment probably February 1949; 5 years' agreement. Candidates, aged 35–50, must have long experience rotary-kiln burning, wet and dry processes; preference given to candidates with knowledge of oil and coal firing equipment.

TWO BURNERS. Salary £600 per annum fixed. Appointment probably February 1949; 5 years' agreement. Candidates, aged 35–50, should have had similar experience to Chief Burner and be capable taking over from him as required.

Cost of living allowance Rs. 70 a month payable in all cases. Posts are non-pensionable, but provident fund exists. Possibility that agreements may be renewed. Government quarters provided at rental of 6 per cent. of salary; free passages out and home for officers and families; leave, travelling allowance, etc., in accordance with regulations. Write stating age, whether married or single, and full particulars of qualifications and experience, and mentioning this paper, to the Crown Agents for the Colonies, 4, Millbank, London, S.W.1, quoting M/N/21442/3E on both letter and envelope.

Copies of "Cement and Lime Manufacture" required for years 1942 to 1946 inclusive. State price. Box 1980, "Cement and Lime Manufacture," 14, Dartmouth Street, London, S.W.1.